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Thermal Considerations for Transportation of Radioactive Material Packages Within the Safe Secure Trailer (SST)

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Thermal Considerations For Transportation Of Radioactive Material Packages Within The Safe Secure Trailer (SST)

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ABSTRACT

Within the Department of Energy (DOE) complex, radioactive materials are contained for shipment in robust transportation packages such as the 9975, 5320, and 9516 (Mound 1 kW). These packages are shipped inside a closed, well insulated conveyance known as the Safe Secure Trailer (SST). To accommodate the significant heat generated by many radioactive materials, the SST makes use of a built-in cooling system to control its closed cargo environment. A postulated loss of cooling within the SST is beyond regulatory performance envelopes, however, such an event may lead to unacceptably high package temperatures. Analytical results from transient thermal analyses of the 9975 and 5320 packages are reviewed in conjunction with provisions of the Mound 1 kW Certificate of Compliance (CoC). This work provides some insight into the behavior of two package designs during a loss of cargo cooling and how the packages may be protected within an SST.

I. INTRODUCTION

Within the Department of Energy (DOE) complex there are several radioactive material transportation package designs certified for inter-site shipment of radioactive materials. This paper addresses the 9975, 5320 and 9516 (Mound 1 kW) packages in the context of the conveyance in which they are shipped.

The 9975 is a well insulated drum package certified for shipment of up to 4.4 kg of plutonium oxides or metals, but no more than a moderate 19 watts of heat. In contrast, the 5320 and Mound 1 kW packages are unique, used primarily for shipment of high heat generating materials including isotopes such as ^{238}Pu. The 5320 is certified for a heat load of up to 203 watts, and the Mound 1 kW (in contrast to its common name) is certified for up to 500 watts. The latter two heat loads are quite substantial, especially considering that a number of these heat source packages may be loaded into a closed conveyance for shipment.

The conveyance used for shipment of plutonium packages within the DOE complex is a well insulated tractor trailer known as the Safe Secure Trailer (SST). During normal SST operation, the interior environment of the trailer is maintained below a set temperature in accordance with the ambient temperature prescribed in 10 CFR 71.71 for Normal Conditions of Transport (NCT). Environmental control is achieved through the SST's primary and backup cooling systems.

Herein, the term payload always refers to the contents of the package, and the term cargo always refers to the packages within the SST.

The three packages addressed here are all certified for compliance with federal law by the DOE. This means that the package designs were evaluated favorably under NCT and Hypothetical Accident Conditions (HAC) in accordance with the regulatory requirements of 10 CFR 71. For fissile materials including the plutonium isotopes these packages are designed to contain, 10 CFR 71.35(c) requires implementation of some special considerations. Among these requirements are special controls or precautions, if necessary, to maintain safety in the event of an accident or delay in transport. Although not specified beyond the basic thermal performance criteria of 49 CFR 173.442, special controls or precautions may be appropriate for shipment of heat source cargoes. For example, if a certified package is subjected to a transportation environment more severe than the regulatory NCT, subsequent performance of the package may be affected adversely. Consider a scenario wherein an SST loses its cargo cooling system for a prolonged period of time.

Loss of cooling means immediate warming of the cargo environment (including walls, floor and ceiling) since heat is released constantly from the packages. The packages themselves also heat up as the temperature of the SST's internal environment increases and impedes heat dissipation from package outer surfaces. Some time after sustained loss of cooling, package operational limits will be exceeded due to increased temperatures. Limits related to radioactive payload containment include maximum normal operating pressure (MNOP) and the temperature of critical seals such as elastomer O-rings. Temperature limits could also be exceeded within non-containment components, such as radiation shielding materials and impact cushioning materials.

For each of the packages addressed here, some duration of cooling loss will produce unacceptably high package temperatures and likely impair package performance. Consequently, loss of cargo cooling within an SST should be considered, and special preventative or mitigative measures may be necessary to avoid potentially unacceptable consequences.

II. MOUND 1 kW SPECIAL MEASURES

An illustration of the Mound 1 kW package is given in Figure 1. The Mound 1 kW is certified for transportation of 500 watts of heat source plutonium, however the Certificate of Compliance (CoC) identifies several special measures to be applied to shipments via SST. These include:

1. A maximum number of packages that may be shipped in an SST.
2. Supplemental cooling measures shall be used in the SST for each shipment.
3. Trailer interior must be no more than a set temperature during loading.
4. Interior temperature must be maintained at a set temperature or less throughout shipment.
5. Interior temperature must be reported to DOE periodically.
6. Depending on the shipment duration, routing restrictions may be in place to ensure the availability of supplemental cooling measures.

These special measures attest to the seriousness of losing the SST's cargo cooling capability during shipment of the Mound 1 kW package(s).

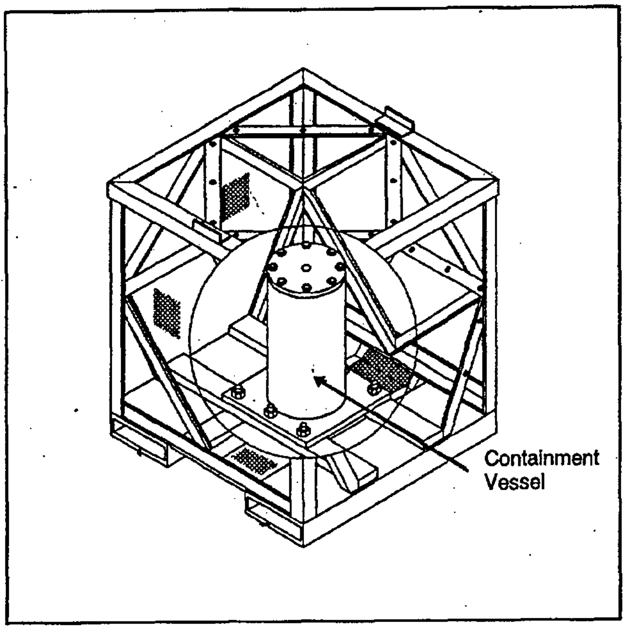

Figure 1 - Illustration Of The 1 kW Package

III. THE 5320 AND 9975 PACKAGES

The 5320 package design was developed in the early 1970s. Since then, the design has been improved, certified and the certificate renewed many times. Currently, the certificate for the 5320 design is undergoing renewal. The 9975 package, however, is a new design and was recently granted a certificate by DOE for compliance with federal law. As part of the certification process, DOE reviewers asked about special measures needed to ensure safety during shipment of the packages within an SST. Hence, thermal analyses were performed to determine the vulnerability of the 5320 and 9975 packages to the effects of a cooling loss during shipment.

To assist reader understanding of the 5320 package design, a cross sectional illustration is presented in Figure 2. The 5320 is certified for transportation of 203 watts of heat source plutonium. The radioactive material is placed within a stainless steel product canister as a handling convenience. The product canister is designated EP-60 and treated as part of the package payload. The Primary Containment Vessel (PCV) designated EP-61, is also stainless steel and contains the EP-60. The PCV is a one-time use vessel, closed for containment by seal welding. The Secondary Containment Vessel (SCV) designated EP-62, is also stainless steel and contains the EP-61. The SCV is closed via flange bolts and sealed by an elastomer O-ring for NCT and a high temperature Flexitallic™ gasket for HAC. Radiation (neutron) shielding is provided by a jacket of water extended polyester (WEP) material. The WEP was poured into the aluminum shield tank and hardened into a solid during packaging fabrication. Aluminum webs within the shield tank provide a good path for payload heat conduction. Outside, vertical aluminum fins surround the shield tank and facilitate heat dissipation to the ambient environment.

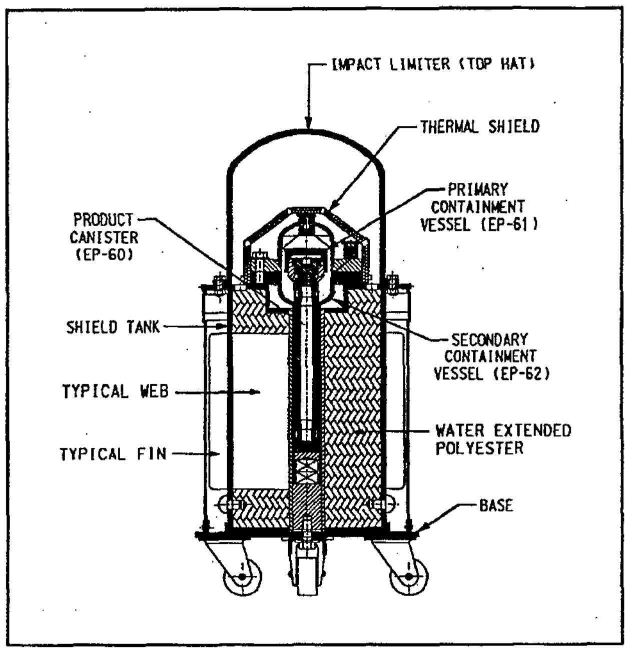

Figure 2 - Cross Section Of The 5320 Package

The 9975, like the 5320, is a double containment package. A schematic representation of the 9975 is shown in Figure 3 to help the reader understand its design. The radioactive payload materials (plutonium metal or oxide) are housed typically within two or three sets of doubly nested food pack cans as a handling convenience. However, the new DOE 3013 storage canister can also serve this purpose. The handling containers are placed into the PVC, and the PCV is placed into the SCV. Both containment vessels are made of stainless steel and closed via screw top lids. Elastomer O-rings provide "leak tight" sealing for each vessel. A layer of lead around the two nested containment vessels provides radiation (gamma) shielding. A cane fiberboard overpack nearly five inches thick surrounds the lead and serves as both structural and thermal insulation. Finally, a 35-gallon stainless steel drum encloses and protects the fiberboard. Because of the low thermal conductivity of fiberboard and corresponding tendency to retain internal heat, the 9975 payload is limited to 19 watts.

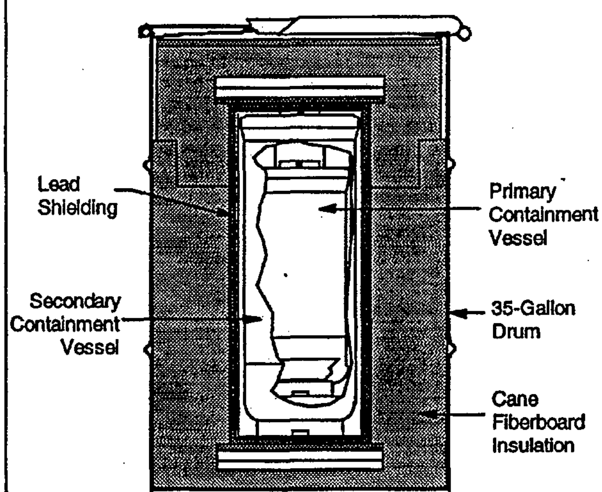

Figure 3 - Illustration Of The 9975 Package

IV. THERMAL ANALYSES

The safety of the 5320 and 9975 packages within an SST during a loss of cooling event is evaluated by computing the shortest time for a critical package component to overheat. Unfortunately, the evaluation becomes virtually unmanageable when the interaction among several packages is considered simultaneously with the internal environment and the SST walls. To simplify the condition to be analyzed and maintain conservatism, consider a single package with an adiabatic shell around it. Hence, SST cooling loss is modeled as an adiabatic "shell" applied instantaneously to the package outer surface. This method of analysis is independent of the total number of packages within the SST and of the SST internal environment.

Part of the evaluation analysis for the 5320 and 9975 packages consists of a transient heat transfer calculation with an adiabatic boundary condition applied to the outer surface of the package. The package initial condition is its temperature distribution and heat load during NCT without insolation.

Internal packaging components, which are reasonably well insulated, will not decrease in temperature instantaneously upon restoration of cooling. Therefore, in addition to loss of cooling, the analysis of the package must also consider reapplication of cooling. Hence, the transient calculation is continued after cooling is restored until peak temperatures are reached within the package. During the cooling portion of the transient analysis, the boundary condition prescribed on the exterior of the package is that for NCT without insolation.

Using this methodology, the response of the 5320 package within an SST to a five-hour loss of cooling is presented in Figure 4. The peak temperatures reached on the package outer surface, WEP, and contents are 224.6°F, 244.9°F, 1315°F, respectively.

The 5320 increases in temperature relatively quickly when the adiabatic boundary condition is applied. The WEP and outer surface temperatures increase at a rate of 18°F/hour and the contents increase at a slower 10°F/hour. The critical restriction for the 5320 package is the

WEP temperature, which is limited to 250°F because of out-gassing behavior.

The WEP temperature limit does not in any way imply potential loss of containment. However, normal package performance may begin to diminish if cooling is not restored within five hours. This consideration will maintain the overall integrity of the package for continued service within the DOE complex.

Like the Mound 1 kW package, shipment of the 5320 within an SST may require stringent operational controls to ensure transportation safety. For example, the route traveled by the SST should be planned carefully to ensure the availability of supplemental cooling measures

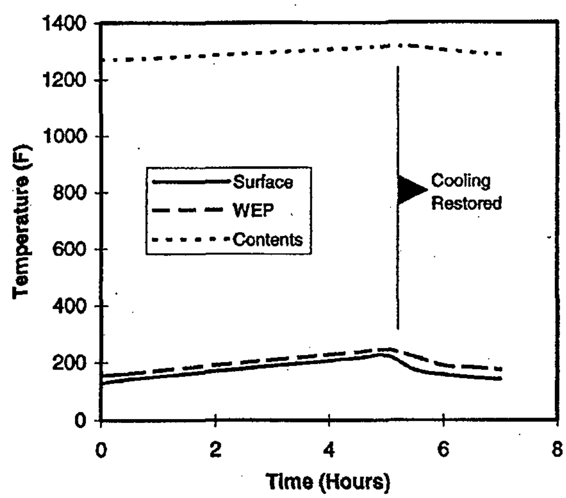

Figure 4 - 5320 Package: Cooling Restored After Five Hours

The response of the 9975 package within an SST to a 36-hour loss of cooling is presented in Figure 5. The peak temperatures reached on the package outer surface, fiberboard, and contents are 197°F, 231°F, 459°F, respectively. Because of the low payload heat generation rate, the 9975 increases in temperature relatively slowly during the adiabatic boundary condition. The outer surface temperature increases at a rate of about 1.9°F/hour and the fiberboard and contents increase at roughly 1.25°F/hour.

The critical restriction for the 9975 package is the temperature of the cane fiberboard. The material begins to out-gas, lose water, and hence, degrade at temperatures approaching 275°F. Because of this behavior, a conservative temperature limit of 250°F for the fiberboard has been specified as part of the 9975 package design.

The 9975 package has sufficient thermal inertia relative to its content heat generation rate to preclude any need for special measures during shipment in an SST. Should loss of cooling occur, the SST crew has 36 hours to remedy the situation.

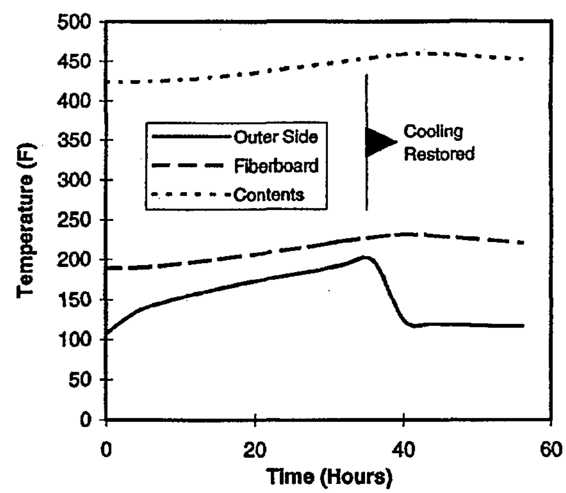

Figure 5 - 9975 Package: Cooling Restored After 36 Hours

V. CONCLUSIONS

Loss of cargo cooling during transportation of heat source packages within an SST is a real concern. Special measures regarding cargo cooling are currently written into the Mound 1 kW CoC to ensure the safety of shipments via SST. Their inclusion in the CoC attests to the serious attention this potential event has received. Supplemental cooling is required at the initiation of Mound 1 kW shipments, and may be replenished during the shipment. Also, the number of Mound 1 kW packages that may be shipped within a single SST is limited to a maximum number.

A relatively simple method of analysis was applied to evaluate the response of the 5320 and 9975 packages to a loss of cooling event within an SST. The thermal transient calculations are conservative and independent of the number of packages within the SST. The response of each package was used to determine if any special measures would be necessary to ensure transportation safety.

The 9975 does not need any special measures because of the relatively low thermal payload limit. However, the 5320 package, like the Mound 1 kW, is used to ship high heat generating materials including isotopes such as ^{238}Pu and requires restoration of cooling within five hours of loss. Actual operational restrictions might be similar to those required by the CoC for the Mound 1 kW package. Such special precautions and controls help to maintain the overall integrity of the packages for continued service within the DOE complex.

VI. ACKNOWLEDGMENTS

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